ГЕОДЕЗІЯ

GEODESY

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EXPLORING THE ACCURACY OF LENGTHS CONSTRUCTIONS WHEN SOLVING THE ENGINEERING GEODESY ISSUES WITH RTN METHOD

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Purpose: This study assumed: experimental determination of the accuracy of measuring relatively short distances, typical for performing survey, planning and marking engineering geodesy works using a dual frequency GNSS receiver under different conditions of observation, and using RTN-technology on mountain area of the Precarpathian region. **Methodology:** To investigate the accuracy of measuring short distances, seven experiments that differed in mutual position of permanent stations and physical geographical conditions of outside conditions were performed. To minimize the sporadic errors and increase the accuracy of obtained results, the investigation in the city of Ivano-Frankivsk was made on the inherent basis, which allows the forced centering of tools. The special aspect of this basis is that it is situated very close to the permanent station (10 km). Observations were made in RTN-mode with the receiver accepting differential alterations from the System Solutions network. **Results:** Results of the study are: obtainment of range accuracy depending on mutual positions of System NET network points; based on testing of the hypothesis about equality of general dispersions of two normally distributed groups, that are receiving an optimum quantity of necessary measurements when building lines areless than 200 m long. **Scientific novelty and practical significance:** It was defined, that the accuracy of building vector's designation with a GNSS receiver under different conditions of observations is always higher than the accuracy of coordinate's designation with the same device; the methodology of bases exploration under different conditions of observation was developed; the optimum quality of necessary measurements on the station in order to provide the given accuracy of results was established; the average square error of line length measurement, which depended on geometry of their location permanent stations.

Key words: GNSS, GNSS-receiver, RTN measurement, coordinates, pseudorange.

Introduction

Today there is a great amount of scientific papers dedicated to measurements in RTN-mode; however, most of these works analyze the accuracy of defining points. It is a necessity to define the distances and angles that is why it is important to study the GNSS observations for conduction such types of tasks. Usually the accuracy of point's definitions is in $\sqrt{2}$ more distinct than distances [Meteshkin, Shaulskii, 2012], however, it does not function when using GNSS observations, as distances and angles are tensor quantities, and accordingly, the influence of systematic errors, the connection with coordinate systems is substantially weaker. If the coordinates of two points is defined with one GNSS-receiver during a relatively short period of time, the influence of errors, triggered by atmospheric and ionospherican isotropy, delays and shifts of complementary dikes and receiver will be significantly decreased because of their systematic components compensation.

It is known that accuracy of RTN-measurements generally depends on distance to the base. To achieve higher accuracy (1–2 cm) RTN should be transferred in radius of less than 30 km [Evstafev, 2009] to the base station. Exactly such accuracy is advertised on the official site ZAKPOS [www.ua-post/net/ZPOS-RTN-v103], and on the official site TOV “TNT TPI” [www.tnt-tpi.com] in RAW service even the obtainable accuracy 0,005 m is featured.

For today, the theoretical and practical issues of acceptance and transmission of differential adjustments in real time and exploration of satellite positioning are studied by scientific centers of Kiev, Lviv, Kharkiv and Chernihiv [Grob, 2006; 2009], that contributed to the development of satellite networks, in particular in Lviv [Lanio, Savchuk, 2012; Savchuk, 2009] and Chernihiv region [Tereshchuk, Nystoriak, 2013].

Aim

The aim is for definition of accurate measurement of line lengths using the GNSS-receiver in the territory of the Precarpathian region and detecting the characteristics of accuracy change depending on the mutual location of permanent stations and their comparison. This work concentrates on accuracy of measurements in RTN-mode.

Methodology

The evaluation of object positioning is usually based on such parameter as phase pseudorange between the satellite and receiver ρ_k, shifting of satellite clocks and receiver $\Delta t, \Delta T_k$, ionospheric $\Delta\rho_k^{ion}$ and tropospheric $\Delta\rho_k^{trop}$ delay, and orbital error conditioned by vague values of $\Delta\rho_k^{orb}$k satellite orbit ephemerides, carrier phase N_k multiplied by length of carrier wave λ and error, conditioned by phase receiver noise and multipathing occurrence ε_k^{Ψ} [Ivanykovych, 2015].

It is known, that the spatial correlation of orbital, ionosphere and tropospheric errors occurs during the usage of differential GNSS mode. It allows to determine with high accuracy the coordinates setting by eliminating such errors as $\Delta\rho_k^{trop}, \Delta\rho_k^{orb}, \Delta\rho_k^{ion}, \Delta t, \Delta T_k$, that are practically removed during the formation of equations of first, second and third divergences of phase pseudorange using the appropriate software of the Center of the network for information processing. That is why it is recommended to use the following formula when evaluating the accuracy of the coordinate's setting of a certain network, for example in [RTNLibver 2.4.2 Manual Takasu, 2013]

$$\Phi_{r,i}^{jk} = \rho_k^{ij} + \lambda(N_k^i - N_k^j) + \varepsilon_k^{\Psi}. \qquad (1)$$

It is important to remember, that when solving the engineer-geodesy tasks, such as observing the deformations of the earth's surface, the main planning works or detailed marking, GNSS measuring should be done close to each other (less than 200 m). Also, after a short period of time, we can assume that the errors of network adjustments in the accuracy of positioning will be also eliminated, including the conventional ΔT_k.

All these prove the necessity to conduct the experimental research of defining the coordinates of vector according to the values of GNSS-signals (explore the accuracy of measurements and capacity of anomalous errors while defining the length of comparably short vector).

System Solutions were taken as the output network of interest. The coordinates of permanent stations that are used by the center of control of the system for defining corrections were applied on the raster in Ivano-Frankivsk oblast or at a distance less than 30 km from it. According to the data published on System.NET the total number of 6 such stations include: Berezhany (Lviv oblast), Buchach (Ternopil oblast), Ivano-Frankivsk, Yaremche, Vyzhnytsa (Chernivtsi oblast) and Dolyna.

According to the coordinates of stations, coverage areas with radiuses 10 and 30 km (fig.1) were built. Based on the analysis of these areas, Ivano-Frankivsk oblast was divided into 4 types:

1. Territory situated at the distance of less than 10 km from the permanent station.
2. Territory situated at the distance of less than 30 km from the permanent station.
3. Territory situated at the distance more than 30 km from the permanent station.
4. Territory that overlaps two or more 30 km areas of coverage.

Accordingly, the task was to define the accuracy of setting out project lengths of lines in RTN mode depending on the area of works, time, and conditions of observations.

Experimental works were performed by using a double frequency GNSS-receiver QStar 8+ (technical characteristics are provided in Table 1) and the electronic total station SouthNTS-350 in different regions of Ivano-Frankivsk oblast under different meteorological conditions. Based on the results of the research for this total station, which are described in work [Burak, et al., 2012], it was defined that the accuracy of measuring distances with less than a 200 m length is characterized by average square error less than 0,3 mm. This accuracy is much more distinct than the value, mentioned in the technical characteristics of the device SouthNTS-350, provided in Table 2.

As a result, taking into account the nature of the task to be solved, results of measuring with total station SouthNTS-350 were considered error-free.

The choice of items was conditioned by the mutual location of permanent stations and conditions, under which the geodesy works were performed: “open horizon”, “loose construction” and “mountain zone”. Further in the work, these objects will be named “A” “B” “C” accordingly. Fig. 1 shows the schematic location of the points (blue triangles) on which the experiments were conducted, with respect to the coverage areas of permanent stations marked with red circles with radii of 30 km and 10 km, with red triangles marked directly by the permanent stations.

The first experiment was held Tysmenytsa region near the following locations:

- Olesiv is located in Tysmenytsa region overlap of two 30 km zones (experiment 1.1 A – “open horizon”)
- Klubivtsi is located in Tysmenytsa region – 30 km zone (experiment 1.1 A – “open horizon”).

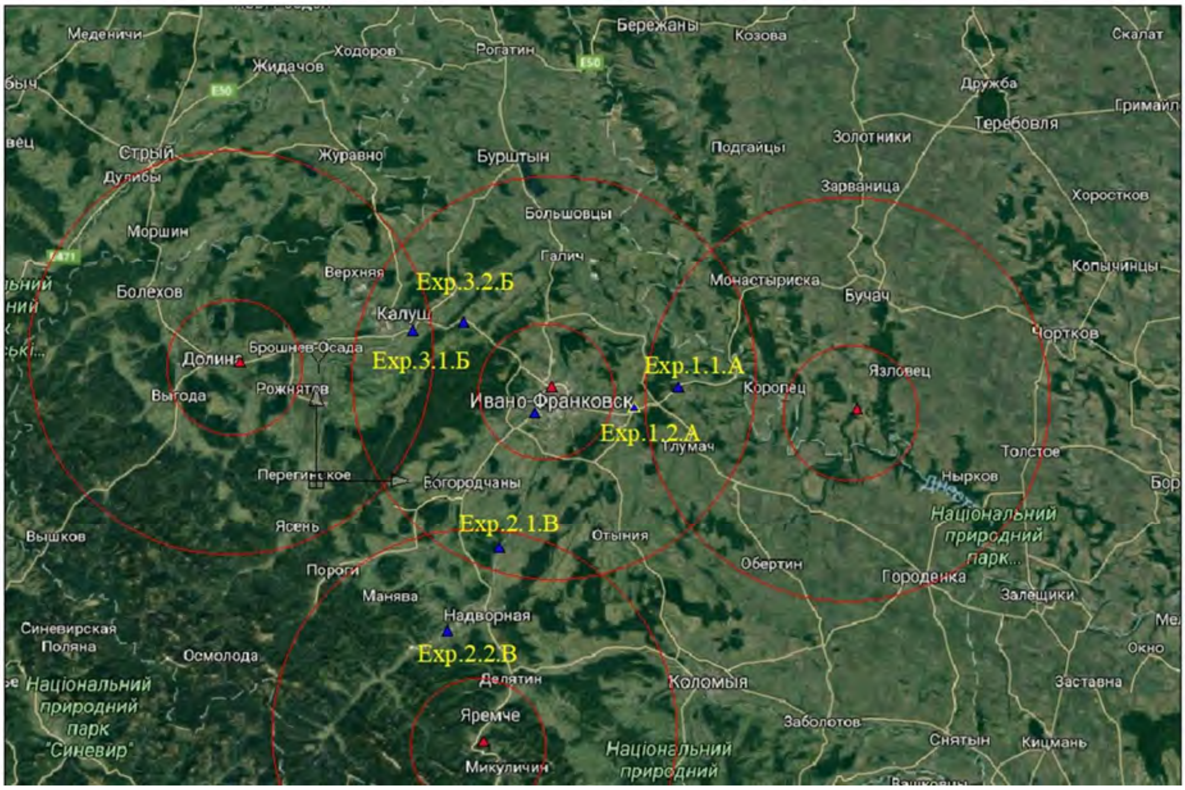

Fig. 1. Schematic Location of monitoring points and permanent stations of the System Solutions network

Table 1

Characteristics of GNSS receiver QStar 8+

Statics accuracy	2.5 mm + 1 mm/km SD
Kinematics accuracy	10 mm + 1 mm/km SD
Number of frequencies	2 (L1/L2)
Number of systems	2 (GNSS/GLONASS)
Number of satellite channels	120
Modems for RTN data receiving / transmitting	GSM/GPRS
Frequency of data recording	1, 2, 5, 10 Hz
Formats of data reception / transmission	RTCM (2.3, 3.0, 3.1), CMR, CMR+

Table2

Characteristics of the South Total Station NTS-350

Minimal countdown	1 "and 5"
Augmentation	30 x
Lens diameter	45 mm (EDM 50 mm)
Field of view	1° 30'
Minimal sight distance	1m
Distance measurement accuracy infrared rangefinder	- 2 mm +2 mm per 1 km
Distance measurement accuracy laser rangefinder 300 m	- 5 mm + 2 mm per 1 km
Distance measurement for one deflector	3 km

Large precise geodesy measurements were made using total station SouthNTS-350, which is described in Table 2. Three telescopic supports were located in the, two of them were equipped with beacons and a third with a total station. Distances were then measured in two rounds, first in straight and then in reverse directions.

Automax technology of RTN was used in the project, alterations of which were calculated simultaneously from several base stations. This technology, developed by the company Leicageosystems, is essential while working in the SystemNET network.

GNSS measurements were done on the same telescopic supports with tribraches, with a previously assembled electronic total station. The admission PDOP (1,5≤) was set for all measurements. After data processing, the distances, received after RTN observations according to the formula (3), where index i means the amount of the measurements made by double frequent GNSS receiver, were calculated. This index alternatively possessed the following values: 5, 10, 15, 30, 60, 300, 600, 900.

After that the differences between distances, measured by both the total station and the double frequency Δ – GNSS-receiver, were determined. The distance, measured by total station $S_{\text{тах}}$ was taken as real for this basis and compared to the distance, and determined with GNSS observations S_{GNSS} with different amount of averages according to the formula

$$\Delta = S_{\text{тах}} - S^{i}_{gps} \quad (2)$$

Results of measurements are provided in Table 3.

Research, described in table 3, were done on 03/06/2016 in two areas in Olesiv on the overlap of two 30 km zones and in Klubivtsi, located in the 30 km. According to the results, distances differed between those obtained by GNSS-measurements and their valid values by measurements done with the electronic total station, ranging from 2 mm Δ to $> 8\,mm$. There is no correlation between the amount of measurements and their difference with real value, that is why the decision not to do experiments while 600 and 900 averages was made.

The data is consistent (for measuring basis with 900 averages approximately per 1 hour is needed) and the study showed that even in 30 km area this does not influence the accuracy of results.

Two other studies were held near the following areas

- v. Fytkiv (Nadvirna region), Kalush (overlap of two 30 km areas)
- v. Zuzyliv (Nadvirna region), v. Vistova (Kalush region) – 30 km area

Figure 1 provides the schemes of basis location and distance to the permanent station. These experiments were done according to the same methods but with some amendments. As mentioned above, measurements with less than 600 averages were used, but the amount of bases was increased by three. This enabled better evaluation of the measurements and increased the interval during static tests. Obtained results of second and third experiment are provided in table 4.

Experiment 2 was made on 06/28/2016 in Nadvirna region village

- v. Zuzyliv – with a 30 km overlap area onto (experiment 2.1 C – “mountain zone”)
- v. Pniv a 30 km area (experiment 2.2 C – “mountain zone”).

This experiment obtained the index B, which means that it was conducted in a mountainous area.

Experiment 3 was made on 09/01/2016 in Kalush with a 30 km overlap (experiment 3.1 B –

"loose construction") and Kalush region v. Vistova village – 30 km area (experiment 3.2 B – "loose construction"). This experiment was carried out in a territory with loose construction that is why it received index B

Experiment 4 was made on 11.13.2016 near Ivano-Frankivsk in 10 km area. A 208 m length base was located in the territory of Ivano-Frankivsk region. These bases were located in the area with open horizon. Results of the experiment are provided in Table 4.

Exploration targets were located in different parts of Ivano-Frankivsk which significantly complicated moving, organization and planning of the measurement process. Accordingly, this experiment was divided into 4 turn-outs, equipped with double frequency GNSS receiver QStar 8+ and South total station. The methodology of experiments on sites A (open horizon), B (loose construction) and C (mountain area) partially conditioned mutual location of permanent stations.

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Table 3

Dependence of distance measurement accuracy on the number of averages on the spot and coverage areas

#of averages	5	10	15	30	60	300	600	900	SD
Δ1	0.0055	0.0054	0.0030	0.0024	0.0078	0.0031	0.0043	0.0083	0.0058
Δ2	0.0024	0.0052	0.0029	0.0025	0.0077	0.0039	0.0040	0.0043	0.0047

Table 4

Dependence of distance measurement accuracy on the number of averages in the spot and coverage area

Location	S	Number of measurements					SD
		5	10	15	30	60	
Exp.1.1.A	64.916	0.0055	0.0054	0.0030	0.0024	0.0078	0.0052
Exp.1.2.A	55.313	0.0024	0.0052	0.0029	0.0025	0.0077	0.0046
Exp.2.1.B	91.195	0.0017	-0.0074	0.0044	-0.0065	0.0055	0.0055
	42.608	0.0085	0.0069	0.0072	0.0055	0.0056	0.0068
	32.857	-0.0048	-0.0052	-0.0053	0.0006	0.0032	0.0042
Exp.2.2.B	74.315	0.0027	0.0065	0.0034	0.0018	0.0030	0.0038
	55.814	-0.0065	0.0017	0.0082	0.0013	0.0008	0.0048
	48.646	0.0044	0.0038	0.0008	0.0055	0.0045	0.0041
Exp.3.1.Б	62.487	0.0053	0.0048	0.0032	0.0067	0.0059	0.0053
	55.312	-0.0025	-0.0022	-0.0044	-0.0043	0.0000	0.0031
	71.548	-0.0056	-0.0009	-0.0054	-0.0049	-0.0015	0.0042
Exp.3.2.Б	47.781	0.0081	0.0017	0.0030	0.0033	0.0035	0.0045
	41.656	0.0091	-0.0015	-0.0023	0.0041	-0.0029	0.0048
	41.209	-0.0073	-0.0001	-0.0034	-0.0048	-0.0001	0.0042
Exp.4.1.A	208.142	-0.0037	0.0013	0.0025	0.0007	-0.0033	0.0026

After analyzing the data provided in table 4, the conclusion to consider each case separately (depending on mutual location of permanent stations) was made. The average error m was found using formula (3).

$$m = \sqrt{\frac{[\Delta^2]}{n}} \quad (3)$$

$$M_m = \frac{m}{\sqrt{n}} \quad (4)$$

Its accuracy was defined according to the formula (4) by connecting their distances to base stations. The results are provided in Table 5.

Results, provided in table 5 indicate that accuracy of defining length is at least 2 times higher than coordinates, according to which they were defined. After results analysis, the testing of hypothesis about equality of general dispersions of two normally distributed groups was made. They were calculated based on the results of measuring according to 5 types of averages (5, 10, 15, 30 and 60).

The procedure of hypothesis testing $\sigma_x^2 = \sigma_y^2$ was reviewed, upon condition of values $x_i$and x_j normalcy. Selected results of distance measuring when 50 average were taken as an average value x_i, it was compared to the selected results with 5, 10, 15 and 30 averages (table 4), that were taken for average value x_j.

Value F (Fisher criteria) was used as a criteria during hypothesis H_0testing and was calculated by the formula (5) for each pair of pickings x_i, x

$$F = \frac{S_{xi}^2}{S_{xj}^2} \quad (5)$$

This value has F-allocation with k = n-–1 and 1 = m–1 number of freedom degrees.

The critical area for hypothesis $H_0$was defined, which is the range of possible values of t statistics that assume deviation having an established level of significance 0.001 (results validity is 99,9 %)

Then a one–sided hypothesis test concerning alternative $H_{-1}$was made. To complete this testing, the mode of two sample F-test for dispersions was used, but Alfa (1–a) was used as a level of significance for average values $x_i$and $x_{j.}$

To compare the results of measuring, the comparison of observation distances with 60 averages with pickings 5, 10 and 30 is provided in Table 6.

Table 5

Characteristics of dependence of measurement accuracy from distance to permanent stations

№	Distance SD SD, м	S_1, м	S_2, м	S_3, м
		Ivano-Frankivsk	Buchach	Yaremche
Exp.1.1.A.	0.0052±0.0023	24028.448	24171.417	65719.97
Exp.1.2.A.	0.0046±0.0023	13912.824	34055.02	56829.28
		Ivano-Frankivsk	Yaremche	Dolyna
Exp.2.1.B.	0.0056±0.0014	26634.481	28073.077	48819.62
Exp.2.2.B.	0.0043±0.0011	11556.252	43155.033	52796.14
		Ivano-Frankivsk	Dolyna	Yaremche
Exp.3.1.Б.	0.0043±0.0011	22499.19	29239.34	65033.81
Exp.3.2.Б.	0.0045±0.0012	17377.109	36691.258	63883.80
		Ivano-Frankivsk		
Exp.4.1.A.	0.0026±0.0012	1341.6018		

Table 6

Example of hypothesis testing

x_j.	5	10	15	30	60
"left-sided" testing of hypothesis H_0 during the level of significance (α)					
F	0.4377	0.7264	0.6976	0.7542	1.0000
P(F<=f) one-sided	0.0671	0.2789	0.2546	0.3023	0.5000
F critical one-sided	0.1686	0.1686	0.1686	0.1686	0.1686
"right-sided" testing of hypothesis H_0 during the level of significance (1- α)					
F	0.4377	0.7264	0.6976	0.7542	1.0000
P(F<=f) one-sided	0.0671	0.2789	0.2546	0.3023	0.5000
F critical one-sided	5.9297	5.9297	5.9297	5.9297	5.9297
SD	0.0055	0.0042	0.0042	0.0040	0.0043

Taking into account the data with left-sided hypothesis testing H_0 during the level of significance (a) (table 6) the following conclusion could be drawn: critical area is written as interval 0; $F_{кр.α}$. In our case, F is the critical one-sided = = $F_{кр.α} \cong (0.4377; 0.7264) \notin (0; 0.1686)$, and that is why the hypothesis is accepted. The deviation of value of critical statistics F (left) from ideal for H_0value F=1 was acceptable taking into account the acceptable level of risk α = 0.001

In the case for the right side H_0hypothesis testing, critical area has taken the shape of open interval ($F_{кр.α}$; + ∞), in our case (5.9297; + ∞). As the critical statistics of F= (0.4377; 0.7264) < < 5.9297, so H_0 is again accepted.

Consequently, the hypothesis about equality of general dispersions was approved, which gives an opportunity to consider the mentioned measuring of equal accuracy. After analyzing the critical statistics of these pickings, it is possible to conclude that measurements received having 5 averages are undesired, because their value of critical statistics F = (0.4377) is the most secluded among all with ideal value of F=1.

Conclusions

Based on the results of undertaken studies by using different GNSS mode, the following conclusions were draw:

The accuracy of defining lines length is at least two times higher than accuracy of coordinates according to which these lengths were defined.

RTN-method allows receiving measured distances with accuracy accessible for modern tachometers, by using double frequency GNSS for defining relative coordinates.

Data for defining distances with GNSS receiver depending on mutual location of permanent stations was analyzed and their RMS error was specified:

2.6 ± 1,2 mm for 10 km area

4.5 ±0.8 mm for 30 km area

5.0 ± 0.9 mm for overlap of two and more 30 km areas

By means of F test for dispersion, the equal accuracy of distances measuring results when 10, 15, 30 and 60 averages was proved. It allows recommending 10–15 averages, which enables optimization of observation time.

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ДОСЛІДЖЕННЯ ТОЧНОСТІ ПОБУДОВИ ДОВЖИН ДЛЯ РОЗВ'ЯЗАННЯ ІНЖЕНЕРНО-ГЕОДЕЗИЧНИХ ЗАДАЧ ІЗ ВИКОРИСТАННЯМ МЕТОДУ RTN

Мета цього дослідження – експериментальне визначення точності вимірювання порівняно коротких віддалей, характерних для виконання вишукувальних, розпланувальних та розмічувальних інженерно-геодезичних робіт, GNSS-приймачем за різних умов спостережень, під час використання RTN-технології на передгірській території Прикарпаття**. Методика.** Для дослідження точності вимірювання коротких віддалей у цій науковій роботі виконано сім експериментів, які відрізнялись взаємним розміщенням перманентних станцій та фізико-географічними умовами місцевості. Для мінімізації випадкових похибок та збільшення достовірності отриманих результатів дослід у місті Івано-Франківськ виконувався на закладеному базисі, який дозволяє примусове центрування приладів. Особливістю цього базису є те, що він розташований безпосередньо близько від перманентної станції (10 км) на відкритій місцевості. Цей фактор практично компенсує систематичні складові похибок у результатах відносних вимірів. Спостереження проводились у RTN-режимі з приймачем, налаштованим на прийом диференційних поправок від мережі System Solutions. **Результати**. За результатами цих досліджень отримано точність визначення віддалей залежно від взаємного розміщення пунктів мережі System Solutions; виконано аналіз можливості під'єднання та отримання фіксованого розв'язку в режимі RTN залежно від зон покриття; на основі перевірки гіпотези про рівність генеральних дисперсій двох нормально розподілених сукупностей знайдено оптимальну кількість необхідних усереднень відліків під час побудови ліній довжиною до 200 м. **Наукова новизна та практична значущість.** Встановлено, що точність визначення побудованих векторів (ліній) GNSS-приймачем за різних умов спостережень завжди вища за точність визначення координат тим самим приладом; розроблено методику досліджень базисів для різних умов спостережень; встановлено оптимальну кількість необхідних усереднень відліків для забезпечення заданої точності результатів; визначено середню квадратичну похибку вимірювання довжин ліній залежно від взаємного розміщення перманентних станцій.

Ключові слова: GNSS; GNSS-приймач; RTN-вимір; координати; псевдовіддаль.

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